White Paper for Blazar Observations with a GEMS-like X-ray Polarimetry Mission

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ABSTRACT

In this document, we describe the scientific potential of blazar observations with a X-ray polarimetry mission like GEMS (Gravity and Extreme Magnetism SMEX). We describe five blazar science investigations that such a mission would enable: (i) the structure and the role of magnetic fields in AGN jets, (ii) analysis of the polarization of the synchrotron X-ray emission from AGN jets, (iii) discrimination between synchrotron self-Compton and external Compton models for blazars with inverse Compton emission in the X-ray band, (iv) a precision study of the polarization properties of the X-ray emission from Cen-A, (v) tests of Lorentz Invariance based on X-ray polarimetric observations of blazars. We conclude with a discussion of a straw man observation program and recommended accompanying multiwavelength observations.

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1. Introduction

Blazars are Active Galactic Nuclei (AGN) with jets (highly relativistic outflows) that are aligned with the line of sight to within a few degrees. Owing to the effect of relativistic beaming, blazars are among the brightest extragalactic X-ray sources and allow us to study their non-thermal jet emission with excellent signal-to-noise ratios (Krawczynski & Treister 2013).

X-ray polarimetry is still an emerging field. NASA has launched so far only one satellite-borne instrument specifically designed for X-ray polarimetry, the Graphite Crystal X-ray polarimeter experiment on the *OSO-8* mission. The polarimeter detected polarized X-ray emission from the Crab Nebula (Weisskopf et al. 1978) but was not sensitive enough to detect polarization from extragalactic X-ray sources. An X-ray polarimetry mission like GEMS (Gravity and Extreme Magnetism SMEX) can access the polarization of the 2-10 keV emission of a 1 mCrab source down to polarization degrees of 2.8% MDP (99% confidence level Minimum Detectable Polarization for a 10^6 s observation) (Black et al. 2010). GEMS was proposed in response to the NASA SMEX announcement of opportunity in December 2008, was selected for phase A development in 2009 and selected for phase B in 2010. Unfortunately, the mission was not confirmed in 2012 owing to the risk of a cost overrun.

A mission like GEMS has the potential to make a number of smoking-gun observations concerning the inner workings of AGN jets:

1. How is the magnetic field in AGN jets structured, and which role does it play in launching the jet, accelerating it, and confining it?
2. Is the X-ray emission from high-energy peaked BL Lac objects indeed synchrotron emission? If yes, is the radio, IR, or optical radiation from the AGN core emitted co-spatially with the X-ray emission?
3. Is the X-ray emission from Flat Spectrum Radio Quasars (FSRQs) and low and intermediate energy peaked BL Lac objects indeed inverse Compton emission, and what is the dominant target photon population for the inverse Compton processes?
4. How are the properties of the sub-pc scale jet (from which the core X-ray emission comes) related to the properties of the kpc-scale jets?
5. Is Lorentz Invariance a low-energy phenomenon?

The objective of this white paper is to describe these science drivers of a GEMS-like X-ray polarimetry mission that operates in the 2-10 keV energy range and to identify measurements that have a high likelihood to make breakthrough discoveries. Furthermore, the document describes the observation strategy and list preparations required to maximize the science return. We describe specific science investigations in Sect. 2. For each investigation, the science drivers are explained, a

list of the best targets is provided, and the required accompanying multiwavelength coverage is discussed. We describe a straw man observation program in Sect. 3, and comment on the termination of the GEMS mission in Sect. 4.

One distinguishes between blazars according to the frequency at which the Spectral Energy Distribution (SED) of the low-energy (synchrotron) component peaks. In the following we use the abbreviations LSP, ISP and HSP to denote low synchrotron peaked ($\nu^{\rm S}_{\rm peak} < 10^{14}$ Hz), intermediate synchrotron peaked (10^{14} Hz$< \nu^{\rm S}_{\rm peak} < 10^{15}$ Hz), and high synchrotron peaked ($\nu^{\rm S}_{\rm peak} > 10^{15}$ Hz) blazars. In the earlier literature, the reader will often find the abbreviations LBL, IBL, and HBL. These names denote the BL Lac subclasses of LSP, ISP, and HSP blazars, respectively.

2. Blazar Science Investigations

2.1. The Structure and Role of Magnetic Fields in AGN Jets

Marscher et al. (2008) and Abdo et al. (2010) reported tentative evidence for optical polarization swings that were associated with γ-ray flares. The authors interpret the observations in the framework of a model in which AGN jets are accelerated and confined by helical magnetic fields. A jet segment moves through a stationary shock, and particle acceleration at this shock gives rise to the observed flaring episodes. As the helical magnetic field of the jet moves through the standing shock the polarization of the observed emission exhibits a swing.

A mission like GEMS has the potential to reveal similar swings in the X-ray regime. The electrons responsible for the X-ray synchrotron emission cool faster than the electrons responsible for the optical synchrotron emission. The X-ray emission regions are probably much smaller and thus more uniform than the optical emission regions. X-ray polarization observations may thus deliver cleaner evidence for the helical magnetic field structure at the base of AGN jets than optical polarization observations. The GEMS energy band is well suited to detect the synchrotron emission of HSPs. Only very few HSPs exhibit readily detectable synchrotron emission at even higher energies. The X-ray observations might detect higher degrees of polarization and/or more frequent polarization swings. If the X-ray polarization indeed shows frequent polarization swings, the observations could prove the helical magnetic field structure at the base of AGN jets, and could thus make a key contribution to our understanding of the formation, acceleration, and collimation of jets.

Figure 1 shows the results of a simulated 300 ksec (80 hrs) GEMS observations of the HSP Mrk 421. For over a decade the source has been one of the X-ray brightest HSPs in the sky. It is a prime target for GEMS as it exhibits high polarization degrees of about $\sim$15% in the optical (Sillanpää et al. 1993). The data in Fig. 1 are shown for 2 hrs bins, assuming that the source is visible for 80% of the time. The calculations assume that the polarization degree of the synchrotron X-ray emission is similar to the polarization degree of the optical emission.

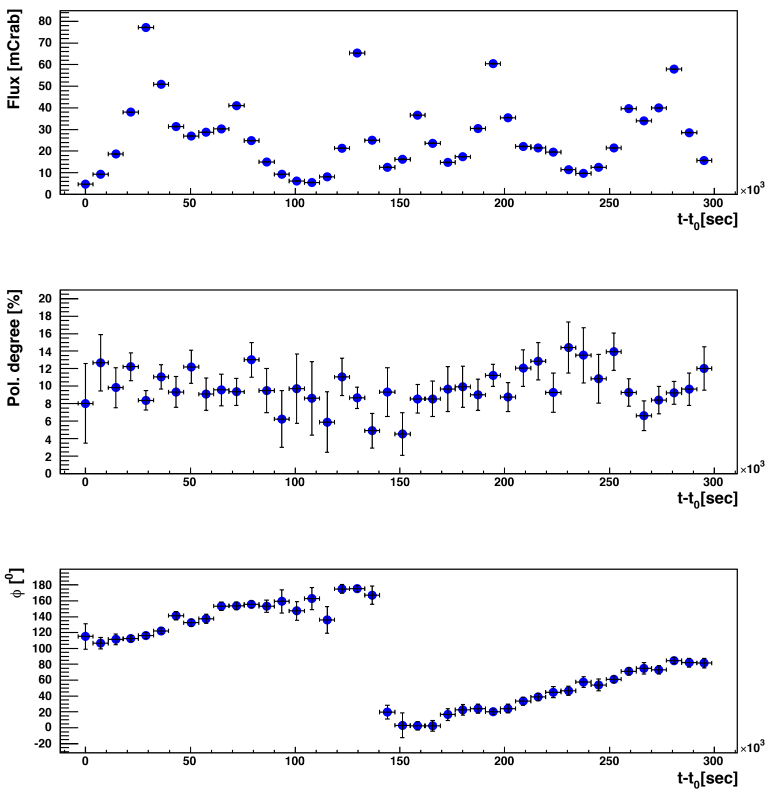

Fig. 1.— Simulation of a 300 ksec GEMS observation of a Mrk 421 flaring epoch. The simulations assume flux levels between 0 and 80 mCrab (upper panel), and a constant polarization degree of 10% (center panel). The polarization exhibits a swing with a rate of $d\phi/dt = 50°$.

In the case of the source BL Lac, Marscher et al. (2008) measured a swing of the optical polarization with a rate $d\phi/dt = 50°$ per day. Our simulation assumed that the X-ray polarization of Mrk 421 behaves in a similar way as the optical polarization of BL Lac as both sources exhibit similar optical polarization degrees (Sillanpää et al. 1993; Tosti et al. 1998). Furthermore, the galactic bulge black hole mass estimates are similar for the two sources: $\approx 2\times\ 10^8$ $M_{\rm sol}$ (Barth, Ho & Sargent 2003; Marscher et al. 2008). We thus expect a similar $d\phi/dt$ for the two sources as the swing rate should scale with the mass of the black hole.

Good targets are X-ray bright and show a high degree of optical polarization. Four X-ray bright objects from the compilation of HSPs and ISPs of Costamante & Ghisellini (2002) are given in Table 1 plus 1ES 1218+304. The table also lists the polarization degree measured in the optical band. Note that blazars exhibit flares with a "red noise" power spectrum. This means that the flux levels change not only on short time scales of a few minutes but also on time scales of weeks, months and years. Ideally, the observation program should be adapted to up-to-date information

Object	Class	z	$F(2-10\,\mathrm{keV})$	opt. pol [%]
Mrk 421	HSP	0.031	48	0-13 (1,2)
Mrk 501	HSP	0.034	24	2-4 (1)
1ES 1959+650	HSP	0.047	<12	nd
PKS 2155-314	HSP	0.116	<12	2-10 (2,3,4)
1ES 1218+304	HSP	0.184	24	5 (3)

Table 1: Target list for the science investigations "The Structure and Role of Magnetic Fields in AGN Jets" and the science investigation "Study of the Synchrotron X-ray Emission from AGN Jets". Column 4 gives the assumed 2-10 keV energy flux levels in units of $\left[10^{-11}\,\mathrm{erg\,cm^{-2}\,s^{-1}}\right]$. A flux of 1 mCrab corresponds to a 2-10 keV energy flux of 2.4×10^{-11} ergs cm^{-2} s^{-1}. References: (1) Angel & Stockman 1980, ARAA, 321, (2) Tosti et al. 1998, A&A, 339, 41, (3) Jannuzi et al. 1993, ApJS, 85,265, (4) Scarpa & Falomo 1997, A&A, 325, 109

about flaring sources. The best strategy will combine archival information (as the one from Table 1) with source activity indicators from ground based and space borne satellites.

2.2. Study of the Synchrotron X-ray Emission from AGN Jets

The most likely emission mechanism responsible for X-ray signals from HSP blazar jets is synchrotron radiation. The polarization of radio and optical synchrotron emission has been used to study the properties of AGNs for decades. Non-thermal emission tends to exhibit larger polarization degrees than thermal emission. A power-law population of quasi-isotropic relativistic electrons (with Lorentz factors $\gamma_e \gg 1$) with a differential distribution $n_e(\gamma_e) \propto \gamma_e^{-p}$ in the *jet frame* generates a degree of polarization P_S of

$$P_\mathrm{S} \;=\; \frac{p+1}{p+7/3}\;\times\;100\% \tag{1}$$

in a uniform magnetic field (e.g. Ginzburg & Syrovatskii 1965; Bekefi 1966; Rybicki & Lightman 1986). This result is realized for a wide variety of pitch angle distributions of the electrons. The basic exception is when the pitch angle lies within the small Lorentz cone of angle $1/\gamma_e$ with respect to the field direction. Then, the Doppler boosting of the dipolar radiation antenna pattern is distinctly different, and a separate regime of small-angle synchrotron emission (Epstein 1973) is realized. This regime, perhaps less likely to be found in jets containing shocks or strong field turbulence, is addressed briefly below. We note that Eq. (1) generally applies also in the *observer's frame*, since the polarization degree is Lorentz invariant. However, the polarization angle is affected by the Lorentz transformation and can result in its rotation between the two frames.

If the X-ray polarimetric observations localize regions of the jet with quasi-uniform magnetic fields, this basic result yields a one-to-one correspondence between the differential photon spectral index Γ such that $n_\gamma(E) \propto E^{-\Gamma}$, and P_S, since $\Gamma = (p+1)/2$. Hence, simultaneous measurements

of polarization and flux in distinct energy bins (at least 4) permit spectropolarimetric probes of the field configuration. In the ideal case described by Eq. (1), flat electron distributions ($p = 0$) yield $\Gamma = 1/2$ and $P_S = 3/7$, already a strong polarization signal. At the other extreme, steep spectra (i.e. turnovers with effective $p \gg 1$ and $\Gamma \gg 1$) yield polarization degrees near 100%. The principal hallmarks of this idealized, uniform (and laminar) field case include $> 20\%$ polarization that is not strongly variable with flux levels over time. In contrast, the polarization angle ϕ can vary in an extended time sampling of blazar X-ray emission (e.g. see Figure 1), in either an organized fashion, such as a sinusoidal sweep expected for helical jet structure, or in a more chaotic manner, corresponding to more turbulent global field morphology within the jet.

A more probable scenario is that the observations only generate good photon count statistics when integrating over blazar source volumes that possess more complicated field morphologies. Then field tangling depolarizes the signal, perhaps down to 5-15% levels, and there is no coupling between spectral index Γ and polarization degree P_s. This reduces the diagnostic capability, but does not eliminate it. Since, within the narrow X-ray window, the effective sampling of turbulent fields by radiating electrons is approximately achromatic, one anticipates the same correlation as in uniform fields: higher polarization degrees are associated with steeper spectra. The actual value of P_s will be a convolution over the integrated field structure. While this can be modeled with subjective choices, it will be difficult to deconvolve observations to unambiguously constrain the field components unless P_s exceeds 30%. However, the polarization angle sweeps $\phi(t)$ with time will probably disentangle static, uniform field structure environments from those where the large scale average magnetic field vector displays an organized, but non-uniform (e.g. helical) geometry. We note also that the signature of viewing perspectives down the mean magnetic field line is low linear polarization coupled with rapidly variable ϕ, i.e. approximating circular polarization. This maps over to large/rapid polarization angle swings in time traces, such as those detected in radio pulsars.

The source candidates of this science investigation are identical to those of the previous science investigation. The candidate sources are listed in Table 1.

2.3. Identify the Dominant Target Photon Population for the Inverse Compton Emission from LSPs, ISPs, and FSRQs

For LSPs, some ISPs, and FSRQs the soft X-ray observations sample the inverse Compton component. The GEMS observations should be able to decide between a Synchrotron Self Compton (SSC) and an External Compton (EC) origin of the inverse Compton emission (Krawczynski et al. 2010; Krawczynski 2012).

In the case that the X-ray emission is of SSC origin, the X-ray inverse Compton emission should exhibit similar polarization properties (polarization degree and polarization direction) as the optical synchrotron emission (Poutanen 1994; Celotti & Matt 1994; Krawczynski 2012). If the

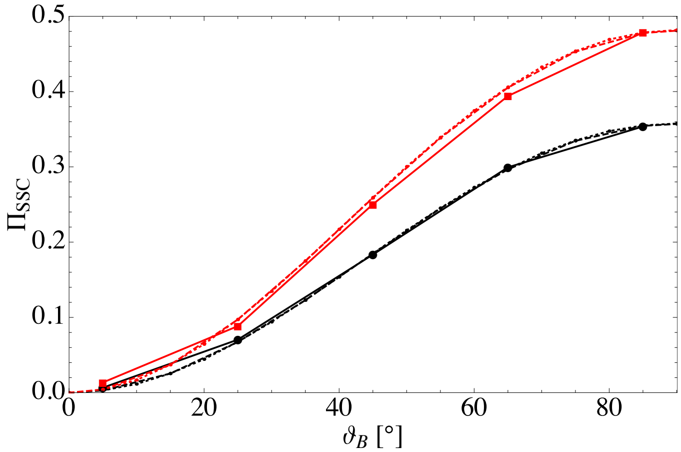

Fig. 2.— Polarization degree of the SSC emission as function of the angle $\vartheta_{\rm B}$ between the magnetic field and the line of sight for a spectral index $\alpha = 1$ of the target photons, and a differential electron number index $p = 3$ (squares), as well as for $\alpha = 0.5$ and $p = 2$ (circles). The lines show various semi-analytic approximation to the polarization degree (see Krawczynski 2012). Results are shown in the "central power law region of the SSC emission", at energies well above and well below the low-energy and high-energy cutoffs of the emission, respectively.

X-ray emission is of EC origin, the X-ray polarization degree is expected to be lower ($\ll$10%) than the optical polarization degree (Poutanen 1994; Krawczynski 2012).

The polarization degree of the SSC emission $P_{\rm SSC}$ can be a sizable fraction of that of the synchrotron emission $P_{\rm S}$ (see Fig. 2) depending on the angle $\vartheta_{\rm B}$ between the magnetic field direction and the line of sight. Given that the synchrotron polarization degrees are usually rather high (close to the most optimistic theoretical predictions), the SSC model definitively predicts a high degree of polarization in the GEMS energy band.

The observations should target a few ($\sim$ 5) sources of the three different source classes LSPs, ISPs, and FSRQs to identify for each of these classes the dominant seed photon population.

Table 2 lists seven source candidates. The sources were the brightest BeppoSAX LSPs and FSRQs in the MECS (2-10 keV) energy band (Donato et al. 2005). All except 3C 273 show high degrees of polarization. For the source S52116+81 we did not find published optical polarization information.

2.4. Closeup view of a misaligned blazar - the case for GEMS observations of Cen-A

At a distance of 3.4 $\pm$0.3 Mpc, Centaurus A is the nearest and best studied radio galaxy. As such, it provides us with an ideal laboratory to examine the physics of relativistic jets, their

Object	Class	z	$F(2-10\,\mathrm{keV})$	opt. pol [%]
BL Lac	LSP	0.069	2	2-23 (1)
ON 231	LSP	0.102	0.4	2-10 (1)
OJ 287	LSP	0.306	0.13-0.24	1-40 (2)
3C 273	FSRQ	0.158	9-11	1 (3)
3C 279	FSRQ	0.586	1	2-43 (4,5)
S52116+81	FSRQ	0.084	1.6	nm
1ES0836+710	FSRQ	2.172	3	15 (5)

Table 2: Target list for the science investigation "Identify the Dominant Target Photon Population for the Inverse Compton Emission from LSPs, ISPs, and FSRQs". Column 4 gives the assumed 2-10 keV energy flux levels in units of $\left[10^{-11}\,\mathrm{erg\,cm^{-2}\,s^{-1}}\right]$. A flux of 1 mCrab corresponds to a 2-10 keV energy flux of $2.4{\times}10^{-11}$ ergs cm^{-2} s^{-1}. References: (1) Angel & Stockman 1980, ARAA, 8, 321, (2) Efimov et al. 2002, A&A, 381, 408, (3) Impey et al. 1989, Valtaoja et al. 1990, Valtaoja et al. 1991, (4) Marscher et al. 2008, Nature, 452, 966, (5) Scarpa & Falomo 1997, A&A, 325, 109

connection with the accretion flow in the center of AGN, and unification models for radio-loud sources. In the radio it shows structures on all resolved scales, starting with the giant radio lobes and two-sided jets that subtend $\sim$10° on the sky, oriented primarily Northeast-Southwest. Based on radio morphology and power it is classified as an FRI.

The host galaxy, NGC5128, is a giant elliptical containing a kpc-scale dust lane which obscures the center. Optical spectra of the nucleus show no evidence for broad emission lines, and Cen A is optically classified as a Narrow Line Radio Galaxy. As the brightest X-ray emitting active galaxy in the sky, Chiaberge et al. (2001) used RXTE data to construct the spectral energy distribution from the radio band through about 100 MeV. The peak of νF_ν is $\sim 10^{42}$ erg s^{-1} at about 100 keV and the luminosity in the 2-6 keV band is about 3×10^{41} erg s^{-1}.

There are conflicting reports of X-ray emission from the giant lobes but the most reliable of these (Marshall & Clark 1981) indicate that there is less than 3×10^{-11} erg s^{-1} cm^{-2} from the giant lobes, or $< 4 \times 10^{40}$ erg s^{-1}. However, these lobes are very diffuse and are well outside the GEMS field of view when the core is targeted. The "inner" jet and the counterjet, extending several arcmin from the core, are detected in ultra-deep Chandra images (Hardcastle et al. 2009), allowing detailed studies of particle acceleration and shocks. The total power in the resolved emission is of order 3×10^{40} erg s^{-1}, or about 10% of the power from the core. Chandra also shows the presence of several hundreds X-ray binaries scattered in the halo of the galaxy Kraft et al. (2009). Integrating the luminosity function of the binaries gives an integrated luminosity of $\sim 10^{39}$ erg s^{-1}, so the binaries contribute less than 1% of the total flux.

The nuclear emission dominates at CCD resolution. A recent Suzaku observation (Markowitz et al. 2007) detects the source up to 250 keV and obtain a 2-10 keV luminosity of 6.7×10^{41} erg s^{-1}. The hard X-rays are fit by two power laws of the same slope, absorbed by columns of

1.5 and $7{\times}10^{23}$ cm^{-2}, respectively. The spectrum is consistent with previous suggestions that the power-law components are X-ray emission from the subparsec VLBI jet and from Bondi accretion at the core, but it is also consistent with a partial-covering interpretation. Below 2 keV, the spectrum is dominated by thermal emission from the diffuse plasma and is fit well by a two-temperature VAPEC model, plus a third power-law component to account for scattered nuclear emission, jet emission, and emission from X-ray binaries and other point sources. Narrow fluorescent emission lines from Fe, Si, S, Ar, Ca, and Ni are detected. The Fe Kα line width yields a 200 light day lower limit on the distance from the black hole to the line-emitting gas. The thermal components are very soft

Fermi recently detected Centaurus A at GeV energies (Abdo et al. 2010), confirming the previous EGRET detection, and by HESS at TeV. The Spectral Energy Distribution from radio to γ-rays can be reasonably well fitted by a misoriented blazar model synchrotron (radio to optical) + SSC (X-rays to GeV) from a one-zone model (Chiaberge et al. 2001); however, the non-simultaneous TeV data are not consistent with the extrapolation from the GeV, lying above it by almost one order of magnitude. This has been interpreted in terms of a spine-sheath jet model with a bulk Lorentz factor of $\Gamma = 2$ in the sheath. As this component will dominate in the soft X-ray band and SSC models generally predict strong polarization (unlike external Comptonization of uniform emission) a detection is deemed likely to provide a very good datum as input for SSC models. The spatial scale will likely be much smaller than even probed on VLBI scales, so the polarization direction should give the orientation of the jet at sub-mas angular scales. Due to variability of a factor of a few, it would be very useful to constrain the high energy portion of the SSC component with NuSTAR or comparable data.

2.5. Search for Lorentz Invariance Violations

For the last two decades theoretical studies and experimental searches of Lorentz Invariance Violation (LIV) have received a lot of attention (see the reviews by Mattingly 2005; Jacobson et al. 2006; Will 2006). On general grounds one expects that the two fundamental theories of our time the General Theory of Relativity and the Standard Model of Particle Physics can be unified at the Planck energy scale. Under certain conditions deviations from the two theories may be observable even at much lower energies, e.g. if effects such as a tiny difference between the propagation speed of orthogonally polarized photons accumulate over cosmological distances to become measurable (Colladay & Kostelecký 1997, 1998).

Possible consequences of LIV are energy and helicity dependent photon propagation velocities. The energy dependence can be constrained by recording the arrival times of photons of different energies emitted by distant objects at approximately the same time (Amelino-Camelia et al. 1998), e.g. during a Gamma-Ray Burst (Abdo et al. 2009) or a flare of an Active Galactic Nucleus (Aharonian et al. 2008). The energy and helicity dependence can be constrained by measuring how the polarization direction of an X-ray beam of cosmological origin changes as function of energy

(Gambini & Pullin 1999).

The detection of a non-zero polarization from a cosmological source at 2 keV and 10 keV constrains the phase difference with an accuracy of $\Delta\phi < \sim \pi$ and would allow us to access group velocity differences down to

$$\frac{\Delta v_{\rm g}}{c} \approx 2\,\Delta\phi(L/\lambda)^{-1} \approx 10^{-35}\,\frac{\Delta\phi}{\pi}\left(\frac{E_\gamma}{5\,{\rm keV}}\right)^{-1}\left(\frac{L}{1\,{\rm Gpc}}\right)^{-1} \tag{2}$$

where E_γ and λ are the mean energy and wavelength of the observed photons.

Equation (2) shows that deviations of the speed of light can be measured with an accuracy proportional to $(L/\lambda)^{-1} \propto E_\gamma^{-1}$. Measurements at higher energies and shorter wavelengths thus lead to better constraints. LIV is thought to be a high-energy phenomenon; the deviation of the speed of light is expected to increase with energy. Using an expansion in powers of E_γ

$$\frac{\Delta v_{\rm g}}{c} = \sum_{n=1}^{\infty} \eta^{(n)} E_\gamma^{\;n} \tag{3}$$

we infer that the accuracies of the birefringence constraints on the coefficients $\eta^{(n)}$ scale as $E_\gamma^{-(n+1)}$. Polarization measurements at X-ray and γ-ray energies enable extremely sensitive tests of Lorentz invariance violating models that predict a helicity dependence of the speed of light (e.g. Gambini & Pullin 1999; Kaaret 2004; Fan et al. 2007; Kostelecký & Mewes 2013). General constraints on the Lorentz violating terms of effective field theories beyond the standard model require constraints form a sample of sources (Kostelecký & Mewes 2009, 2013). A GEMS-like mission could deliver such constraints for a sample of AGNs.

3. Proposed Observation Program

A tentative observation program for a 9-month GEMS-like mission could look as follows:

1. We envision a snapshot survey with relatively short (∼20 ksec) exposures at the beginning of the 9-month observation window. For each of the six science investigations, we envision to observe all the candidate sources listed in Table 1 and 2 plus Cen A. For 10 mCrab sources, the observations would allow us to detect polarization degrees down to 2%. The observations could establish a baseline for later observations. For science investigations #1 and #2 the observations would show which sources exhibit high degrees of polarization.

2. The initial snapshot survey should be combined with a alert-driven target of opportunity (ToO) program. If a sources goes into a bright flaring phase it could be observed for 5 days with 40 ksec observation time each day.

3. In addition to the snapshot survey and the alert-driven ToO program, we recommend deep observations of three key sources, i.e. Mrk 421, Cen-A, and 1ES0836+710. The Mrk 421

Object	Class	z	$F(2-10\,\mathrm{keV})$	Obs. Time [ksec]	MDP [%]
Snapshot Survey					
Cen A	RG	0.0018	13	20	6.7
Mrk 421	HSP	0.031	48	20	5.4
Mrk 501	HSP	0.034	24	20	7.7
1ES 1959+650	HSP	0.047	4.8	20	17.3
PKS 2155-314	HSP	0.116	12	20	10.9
1ES 1218+304	HSP	0.184	24	20	7.7
BL Lac	LSP	0.069	2	20	26.8
3C 273	FSRQ	0.158	9-11	20	12.0
S52116+81	FSRQ	0.084	1.6	20	30.1
1ES0836+710	FSRQ	2.172	3	20	21.9
Target of Opportunity Observations					
tbd	-	-	-	200	-
tbd	-	-	-	200	-
Deep Observations of Key Sources					
Mrk 421	HSP	0.031	48	600	0.8
Cen A	HSP	0.031	13	200	1.8
1ES0836+710	FSRQ	2.172	3	600	3.3

Table 3: Proposed observation program. The total observation time is 2,000 ksec. Column 4 gives the assumed 2-10 keV energy flux levels in units of $\left[10^{-11}\,\mathrm{erg\,cm^{-2}\,s^{-1}}\right]$. A flux of 1 mCrab corresponds to a 2-10 keV energy flux of 2.4×10^{-11} ergs cm^{-2} s^{-1}.

observations will be used to carry through the science investigation #1 and #2. Cen-A is a unique target owing to its proximity and its X-ray brightness; it would allow us to address science investigation #4. 1ES 0836+710 is an attractive target for science investigation #3 and #5.

4. Epilogue

GEMS was proposed in response to the NASA SMEX announcement of opportunity in December 2008, was selected for phase A development in 2009 and down selected for phase B in 2010. A technically successful Preliminary Design Review was held in Feb 2012. NASA Science Mission Directorate (SMD) indicated their intention to non-confirm (or cancel) in May 2012; the SMD decision was based on concerns that the eventual cost would be too high.

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